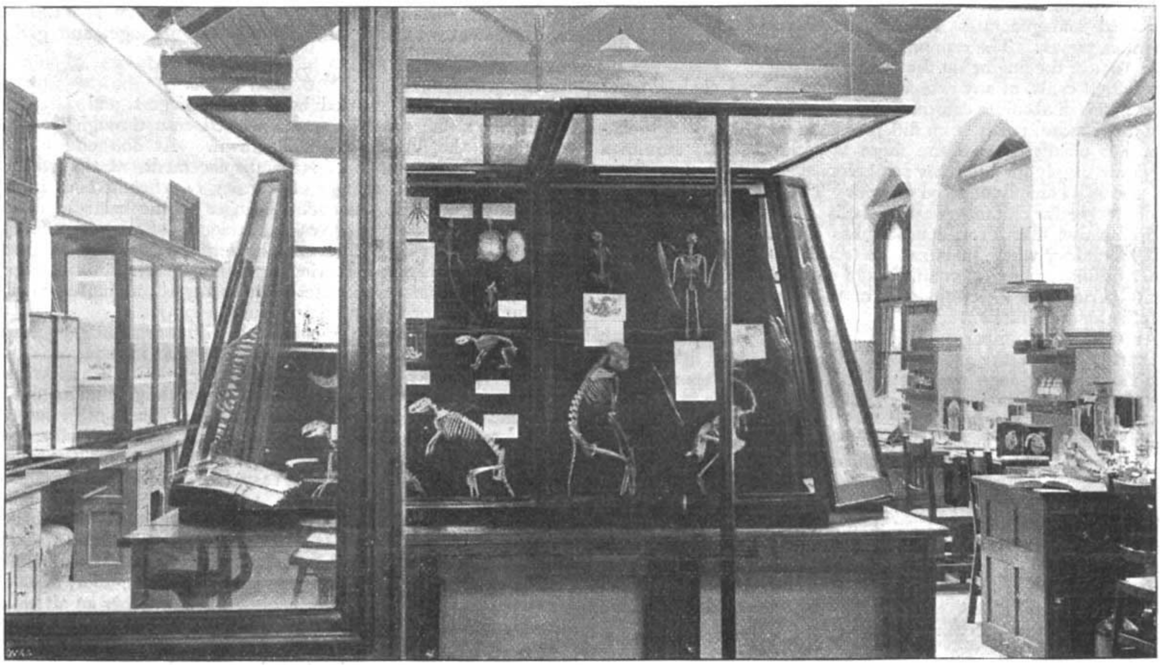
ments are peculiar, but—I may be allowed to say—most successful. The greater part of the room, which is 40 feet long by 21 feet wide, is occupied by cases which contain preparations and specimens under the headings of (*a*) Form and Locomotion, (*b*) Alimentation, (*c*) Circulation and Respiration, (*d*) Nervous System and Sense Organs, and lastly, objects displaying the main lines of classification. In fact, a collection modelled, both as to cases and modes of display, on the same lines as the admirable Introductory Collection of Sir William Flower at the Natural History Museum. It is, of course, on a miniature scale, and it is not yet complete. Beyond the main laboratory is a smaller room temporarily occupied for another purpose.

It now remains for me to add some attempt at a description of the general appearance of these laboratories. In the main, one may say, there is an air of dignity about the lofty and well-proportioned rooms, with their substantial and costly fittings. The woodwork is pitch-pine topped everywhere by thick teak. In the biological museums the cases are of mahogany, and perfectly constructed. Most of the teak tops of benches and tables are thinly coated with paraffin as a preservative. It is still important that rooms devoted to scientific work in schools should be exceptionally neat and bright in appearance. Indeed, it may even be said that appearances are at present more important than anything else as regards the value attached to the subject. Manners must grow to match the clothes. We have to bear in mind that we labour in the cause not of science alone, but of science as an instrument of school training. The laboratories are all *en suite*, whereby control is more easy, and a feeling of organic unity gained. Moreover, the workshops are within touch of the laboratories, as is also the large drawing-school.



A Case of Specimens in Biological Laboratory, illustrating Form and Locomotion.

Finally, I may mention that all the water and waste system has been laid down in direct contravention of all the best traditions of plumbing, with the happy result that we never need the services of a plumber for repairing.

ALFRED EARL.

THE DEVELOPMENT OF THE EXPERIMENTAL STUDY OF HEAT ENGINES.[1]

IT was Mr. Forrest's intention that the annual lecture bearing his name should illustrate the dependence of the engineer in his practical professional work on the mathematical and physical sciences. It therefore naturally takes the form of a review of some branch of engineering with special reference to the scientific principles which have been factors in its advancement.

Twenty years ago, Lord Armstrong stated that of all the coal raised in this country about one-third was used for household purposes, one-third for generating steam, and one-third for iron-making and manufacturing processes. He remarked that in the two first divisions the waste of fuel was shameful, and that without carrying economy to extreme limits, all the effects now realised from the use of coal could be obtained by an expenditure of half the quantity. The improvement of the steam engine is mainly due to an incessant attempt to diminish the waste of fuel.

Tests of Steam Engines in Cornwall.

Steam engineers have been face to face with the problem of economy for more than a century. Coal was excessively dear in Cornwall, and as the mines were deepened and more power was required, the cost of working increased ruinously. By reducing fuel cost, Watt saved the mining industry from extinction, and he adopted the plan of taking in payment for his engines a sum reckoned equivalent to one-third of the fuel saved. By agreement with the miners, tests were made, and the standard duty of a Newcomen engine was fixed at 7,037,000 foot lbs. per bushel. Regular duty determinations were made for all Watt's engines. Generally they gave a duty of 20,000,000. When Watt's connection with Cornwall ceased in 1800; the duty determinations were neglected, and the engines deteriorated.

Then Captain Joel Lean, who had reorganised the machinery at one of the mines, and effected great economies, started again the system of duty trials. He and his sons carried on the work for many years, and published reports of the results of the trials. Of these reports Dr. Pole says: "The publication produced an extraordinary effect in improving the duty of the engines. Engineers were stimulated to emulation amongst themselves. The practice of reporting is thought to have been attended with more benefit to the county than any other single event excepting only the invention of the steam engine itself."

I shall show later that the creation of a new and more scientific system of testing by Hirn and his colleagues in Alsace, in 1855, was the starting-point of a similar process of improvement. Quite lately there has been a revival of careful and independent engine testing and of the publication of the results, and records have been established which would have been thought impossible ten years ago.

The peculiar character of the load against which the Cornish engine worked, the lifting of a heavy mass of pump-rods, contributed to force the use of expansive working. To work without shock, a large initial and gradually diminishing effort was necessary. The extraordinary economy obtained was due probably in part to the special action of the steam, the Cornish engine being virtually a compound engine, and the admission surface being protected from cooling to the condenser; partly to the great effectiveness of a steam-jacket in an engine which worked slowly and with pauses at the end of the stroke, partly to the small clearance and separate admission and exhaust valves. The lesson engineers should have learned from Cornish experience was that in restricted conditions high ratios of expansion were economical. In this case, as in others, later engineers generalised too crudely, and concluded that expansive working was always economical. A new scientific investigation was required to correct the error.

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[1] Abstract of the "James Forrest" Lecture, delivered at the Institution of Civil Engineers, May 2, by Prof. W. C. Unwin, F.R.S.

Experiments on Boilers.

To generate steam power economically the boiler must be efficient, and the engine must be efficient, and the conditions of efficiency of boiler and engine are completely independent. Hence the early method of Watt, in which attention was paid only to fuel used and water pumped has been replaced by a method of independent boiler and engine testing. The boiler uses coal and generates steam; the engine uses steam and generates power. The economy of the boiler is reckoned on the fuel; that of the engine on the steam.

Different coals, at any rate the better kinds of coal, do not differ much in absolute calorific value. Used in boiler furnaces, they differ more, partly from differences of mechanical aggregation, but chiefly because the more bituminous coals require a larger air supply for tolerably smokeless combustion than those which consist chiefly of fixed carbon. The greater excess of air involves greater chimney waste. It is to test the commercial calorific value that Prof. Schröter has established in Munich a heat laboratory where fuels can be tested on a large scale and under ordinary practical conditions of combustion. The arrangements permit the determination of the exact conditions most suitable for each fuel.

An enormous number of boiler trials have been carried out, but most of them are mere individual tests of very little scientific value. Engineers have been too much under the impression that the evaporation depended chiefly on the type or proportions of the boiler, or the arrangement of the heating surface. But there are no obscure or complicated actions concerned in generating steam. Boilers of all types give nearly the same results, provided only proper conditions of combustion are secured. They may differ in cost, in durability, in convenience, but in efficiency they differ less than I think is commonly assumed. The following table shows that boilers of extremely different types, with very different proportions of heating surface and very different rates of combustion, and even with different coals, have all reached evaporations of from 11 to 13 lbs. of water from and at 212° per pound of coal:—

Boiler Trials.

Type.	Ratio of grate to heating surface.	Coal per sq. ft. of grate per hour.	Evaporation from and at 212° per lb. of coal.	Coal.
Cornish ...	—	7·2	11·9	Welsh
Lancashire ...	1 : 36	22·9	11·2	Lancashire
Galloway ...	1 : 24	8·5	11·6	Anthracite
Portable ...	1 : 69	12·8	11·8	Welsh
Tubular ...	1 : 46	10·8	11·9	Anthracite
Babcock ...	1 : 38	8·9	11·8	,,
Marine ...	1 : 34	22·4	12·9	Welsh
,, ...	1 : 50	25·5	12·5	Lancashire
Thorneycroft	1 : 70	7·7	13·4	Welsh
,,	1 : 61	18·6	12·5	,,

Mulhouse Trials of 1859.

The earliest boiler trials carried out in a completely satisfactory way were those made by the Société Industrielle of Mulhouse in 1859. The Society offered a prize to the maker of any boiler which would evaporate 1800 lbs. per hour, at 75 lbs. per square inch pressure, and which would evaporate 9·1 lbs. of water, from and at 212°, per pound of Alsatian coal of not very good quality. With the coal used in these trials, 130 cubic feet of air per pound of coal are chemically necessary for complete combustion. It was found that the reduction of the air supply almost to this limit, and to a point at which there was definitely incomplete combustion, reduced the chimney waste and increased the efficiency of the boiler. In two special trials, each of a week's duration, the evaporation was 9 lbs. with 331 cubic feet of air, per pound, and 9·53 or 6 per cent. more with 247 cubic feet.

The determination of the air supply to a boiler is not altogether an easy operation. An anemometer was used in Alsace, and in suitable conditions it will give approximately accurate results. In recent trials chemical analyses of samples of the furnace gases have been made, and the amount of air supplied calculated from the percentage of CO_2. This method is accurate in principle, but the samples analysed are a very minute fraction of the total chimney discharge, and the samples may not be average samples. In some trials in which this method has been used, there are discrepancies in the ratio of the chimney loss and the undetermined loss, chiefly due to radiation, difficult to understand. Neither anemometer nor chemical analysis is suited to serve as a means of regulating the air supply in the ordinary working of a boiler. What is wanted is an instrument as easily read as a pressure gauge, and giving continuous indications.

The Dasymeter.

The dasymeter, invented by Messrs. Siegert and Durr, of Munich, is a fine balance in an enclosed case through which a current of the furnace gases is drawn. At one end of the balance is a glass globe of large displacement, at the other a brass weight. Any change of density of the medium in the chamber disturbs the balance. A finger on the balance moving over a graduated scale gives the amount of the alteration of density. An air injector draws the furnace gas from the flues, and it is filtered before entering the balance case. An ingenious mercurial compensator counterbalances any effect due to change of temperature or barometric pressure.

The dasymeter is usually combined with a draught gauge, and an air thermometer or pyrometer in the flue is required if the amount of waste heat is to be calculated. The dasymeter requires, initially, exceedingly delicate adjustment, and its indications must be checked from time to time by a Bunte's burette. It is set to read zero with pure air, and then any increase of density due to CO_2 is read as a percentage on the scale. When in adjustment, it is as easy to read the percentage of CO_2 in the furnace gases as to read the pressure on a pressure gauge. When the dasymeter is fitted to a boiler, the stoker has directions to adjust the supply of air so that the furnaces gases have about 12 per cent. of CO_2. With practice he learns what alterations of the damper or fire-door, or thickness of fuel on the grate, are necessary, or whether an alteration of grate area is desirable. After a little time the percentage of CO_2 can be kept very constant.

Isherwood's Experiments on Marine Engines.

About the year 1860, Mr. Isherwood, Chief Engineer of the United States Navy, began a series of systematic tests of engines and boilers on a very large scale, and with resources only available in a Government establishment. The trials were made with skill and determination, and the substantial accuracy of the results, startling as they were, has never been questioned.

All Isherwood's trials of large marine engines showed that when expansion was extended beyond exceedingly small limits, it caused not an economy, but a waste. In his second volume he sums up his results as proving that when cut-off is earlier than 0·6, or perhaps even 0·7 of the stroke, the consumption of steam reckoned on the work done is increased. Curiously enough, this led him to attack the compound engine. From the quantities in the table of experiments, he says, "it will be seen how useless in point of economic gain is the preposterous arrangement of steam engine known as the double cylinder, Woolf, or Hornblower engine. . . . Opposed to these facts, the declarations of interested patentees and engine builders must be classed in value with those set forth by quacks in advertisements of their nostrums." This is from a paper dated 1865, and it is curious, because Isherwood generally saw clearly enough the danger of drawing sweeping conclusions from narrow experimental premises.

The proper lesson from Isherwood's results was merely that certain conditions must be observed to secure economy in expansive working. Unfortunately, more generally the conclusion was drawn that the Cornish results were not to be trusted, and that expansion was not economical, and Isherwood's own language lent authority to the least accurate view of his results. To obtain greater insight into the true action in the cylinder, and to find a reconciliation of the Cornish and American tests, experiments of a much more refined character were wanted and insight due to wider scientific knowledge.

The Physical Properties of Steam.—Regnault.

No useful progress could be made with a theory of the steam engine, no accurate reduction even could be made of the results of engine tests without exact determinations of the relations of pressure, temperature, volume, latent heat and liquid heat of steam. It was fortunate, therefore, that about 1840 M. Regnault obtained the means from the French Government to make a series of researches on the physical properties of steam with splendid instrumental appliances. He wisely carried out his determinations over a very wide range of conditions, and spared no labour or trouble in attaining accuracy. Regnault's results were of the greatest importance as a foundation for accurate study of the steam engine.

The Foundation of Thermodynamics.—Carnot and Joule.

The next important step was the discovery of the equivalence of heat and work. Joule's investigations began with an attempt to improve Sturgeon's magnetic engine. He was so led to consider motive power problems from the engineer's standpoint, as a question of duty, or of something obtained for something expended. He ascertained the amount of electric current produced by the chemical combustion of a given amount of zinc, and comparing his results with those obtained in good steam engines, he concluded that, making the largest allowance for possible imperfections of his magneto engine, it was never likely to be a rival in economy to the steam engine. That was a negative but a useful result. It closed one direction of useless endeavour only too likely to attract the inventor.

One of the effects of electric action which Joule noticed was the heating of his conductors, and it was to the measurement of this heating effect he next addressed himself. The heat developed in the conductor by the electric action due to elements combining in the galvanic cell was found to be identical with that which would be generated by the direct combustion of the same elements. Finally, he came to consider the relation between the mechanical work expended in driving a magneto electric machine, and the heat developed in the external circuit of the machine. He concluded that for 838 foot lbs. expended a pound degree of heat was generated. Later experiments corrected this value, but the discovery of the equivalence of heat and work was made.

As early as 1824, twenty years before Joule's discovery, Sadi Carnot, in a remarkable pamphlet on the "Motive Power of Heat," demonstrated the fundamental principle that the amount of work obtainable from any given quantity of heat cannot exceed a quantity proportional to the fall of temperature. Unfortunately adopting, though with hesitation, the view held in his time that heat is material and indestructible as heat, he coupled with his true principle the false corollary that all the heat entering an engine is discharged in the condenser. Joule, in 1845, found this principle of Carnot, and looking to the corollary as essential, supposed the principle itself to be false. He failed to perceive that Carnot's principle was the essential supplement to his own discovery, and that it showed why the apparent efficiency of the steam engine is so low. It took six years before Joule's and Carnot's principles were reconciled, and for three of them even Lord Kelvin refused to accept Joule's discovery, because it apparently conflicted with the principle of Carnot.

The Founders of the Rational Theory.—Rankine, Clausius, Zeuner.

The impetus given to the study of thermodynamics by the discovery of Joule, and the perception of the fundamental importance of Carnot's theorem, was enormous. Heat problems could now be brought out of the region of mere empirical solutions, and treated from the rational standpoint of an exact science, and the steam engine, as the most important example of heat transformation, attracted at once the attention of scientific men of commanding intellectual ability. In a very few years Rankine and Clausius had built up a strictly rational mathematical theory of the steam engine, and, a little later, Zeuner carried further the analysis of some of the more subordinate details. The theory with one exception, to be referred to presently, took account of all the actual conditions under which steam is used, and furnished exact rules for the relation of steam expended and work done for all arrangements of the actual steam engine practically adopted.

It was just at this time that the experiments of Isherwood were published, and a comparison of experimental results and theoretical calculations showed directly a very large discrepancy. The steam consumption in some trials was 30, 40 or 50 per cent. more than it should have been in the assigned conditions of working according to the rational theory. Some action of quite governing importance had obviously been neglected in the theoretical analysis.

The Experimental Theory.—Hirn and the Alsatian School.

A year or two before Isherwood began his experiments, an Alsatian engineer, M. Hirn, had discovered and measured cylinder condensation.

Joule's discovery attracted Hirn's attention, and he set to work in 1854 to verify, by an exact engine test, whether the difference between the heat received by an engine and discarded in the condenser was the equivalent of the work done. His two most important memoirs relating to the steam engine, are a memoir on the utility of steam-jackets in 1855-6, and another on the use of super-heated steam in 1857. In these researches he devised a method of accurate engine tests, involving the measurement of all the quantities of heat received by or rejected from the engine, which, with hardly any change at all, is the method of accurate engine testing adopted ever since. Under his influence and direction, engine tests were carried out in Alsace for many years, and the results exactly analysed. It may be recalled that the admirable series of engine tests, the first tests in which the heat quantities were accurately measured in this country, which were made by Mr. Mair Rumley, and described in three papers on "Independent Engine Tests" in the *Proceedings* of this Society in 1882, 1885, and 1886, were trials carried out strictly in accordance with Hirn's methods.

As with Lord Kelvin, so with Hirn. It was the recognition of an apparent conflict of Joule's discovery with Carnot's law which first attracted his attention. It was the attempt to determine whether part of the heat supplied to an engine disappeared as work which determined the form of his trials. His experiments of 1854 showed that "heat in a steam motor is not only dispersed, but actually disappears, and the power obtained is exactly proportional to the heat which disappears as heat to reappear as motive power." Some rather later and more careful experiments enabled him to verify Joule's equivalent by the actual results of a large engine test to an accuracy of about one per cent.

The discovery of initial condensation, and the proof of the powerful action of a small amount of heat transmitted from the jacket, both pointed to the conductivity of the cylinder wall as the cause of the large waste of steam which the constructors of the rational theory had neglected. The cylinder is cooled during expansion, and still more during exhaust by an action analogous to internal radiation to the condenser. Before any work can be done in the next stroke, the wall has to be reheated by condensing fresh steam. The extreme facility with which steam yields or abstracts steam by condensing and evaporating, accounted for the rapidity of the action. The magnitude of the condensation increases with the range of temperature to which the cylinder wall is subjected. It is larger in condensing than in non-condensing engines, and larger with high ratios of expansion.

Some time ago I ventured to say that there was no trustworthy engine test which showed that the consumption of steam with a jacket is greater than without the jacket. I believe that is still true, but undoubtedly the economy due to the jacket varies in different cases from 30 per cent. to very nearly zero. Roughly, the jacket is more useful with small engines than with large; with slow engines than with fast engines; but all this amounts to little more than saying that the jacket is most useful in those cases where the initial condensation is largest. Just in proportion as the engine, whatever its type, is of the highest class and most scientific design, the jacket is less useful.

The jacket reduces, but it does not prevent initial condensation. Hirn looked for some more powerful way of heating the cylinder wall without causing condensation; he found it in superheating. He constructed, in 1855, a super-heating apparatus in the flues of the boiler at Logelbach, which still exists. The experiments with super-heated steam were carried out between 1855 and 1856, and showed clearly the effectiveness of the method in reducing condensation. Super-heating came largely into use in the years 1860-70 in this country in marine engineering, the practice having been introduced here by John Penn. In every case in which it was used an economy of coal was realised. Generally the economy amounted to from 15 per cent. to 20 per cent. It was ascertained that this was due strictly to economy of steam, and not to the utilisation in the boiler of heat previously wasted. But the use of super-heated steam in this country was gradually abandoned, partly no doubt from some practical difficulties, but chiefly, I believe, because practical engineers had no clear idea why super-heating should produce so large an economy, and they were not indisposed to abandon a complication, the action of which they could not satisfactorily explain to themselves.

No possible improvement of the steam engine, of which we have any knowledge at this moment, offers anything like so great a chance of important economy as the reintroduction of superheating, and especially of super-heating to at least 100° or more above the saturation temperature of the steam. I obtained in Alsace on a very good 500 H.P. compound mill engine with jackets, and every appliance for economical working, an economy of 15 per cent. Mr. Mair Rumley has fitted a super-heater to a Babcock boiler supplying a triple engine, and has obtained an economy of 10 per cent. In both cases the economy is economy of steam, and therefore is not due to any increase of boiler surface or increase of efficiency in generating the steam. Lately Prof. Schröter, of Munich, has been experimenting with a small special compound condensing engine of only 60 I.H.P., running at the moderate piston speed of 380 feet per minute, and with the not excessive boiler pressure of 165 pounds per square inch. The H.P. cylinder is not jacketed. The L.P. is jacketed with receiver steam. In this case in a tube super-heater of a rather special construction in the uptake of the boiler, the steam is superheated to 670° F., or nearly 300° above the saturation temperature corresponding to the pressure. In two trials of six and eight hours' duration, periods quite long enough for accurate determination of results with so accomplished an observer as Prof. Schröter, the consumption of steam was only 10·2 pounds per I.H.P. hour, and the consumption of German coal of moderate quality only 1¼ pounds per I.H.P. hour. The steam consumption is the lowest on record for any engine of any type or size, and is very remarkable for so small an engine.

Conflict of the Rational and Experimental Theories.—Zeuner, Hirn, and Hallaner.

On the appearance of Isherwood's researches in 1863, the discrepancy between the rational theory and the results of experiments was recognised by Rankine and others. But the conditions of cylinder condensation are so complex, that for a long time the more theoretical writers practically ignored both Hirn's and Isherwood's results. Zeuner, perhaps, had pushed the rational theory to the furthest limit of detail, and with the greatest insight into practical conditions. But it was not till 1881 that he began to explicity admit the largeness and importance of the condensing action in the cylinder. Zeuner then was disposed to attribute initial condensation to the presence of a permanent and not inconsiderable mass of water in the clearance space of the engine. No doubt it is simpler analytically to deal with the thermal changes of the steam plus a given mass of water than with the thermal changes of steam, water, and a varying area of solid cylinder wall. In opening a discussion with Hirn in 1881, Zeuner wrote that if the presence of water in the clearance space was conceded, the Alsatian calculations would be greatly shaken, and "the enormous influence which they attributed to the cylinder wall would in future be attributed in part, perhaps chiefly, to the water in the clearance space." He thought it conceivable that in certain cases the whole of the initial condensation was due to water in the clearance space. There thus arose a rather angry controversy, which has been summed up in the question, "Is it water or iron?" I do not know that this controversy has been as yet completely decided, or that perhaps an absolute decision is possible. I cannot help thinking that Hirn, with the clearness of view due to his experimental work, had on the whole the best of the controversy, and I do not know that anything better or more instructive can be said than the words in which he finally summed up his position. "We recognise," he said, "that the interpretation of the Alsatians differs from that of M. Zeuner, not at all in that it denies the possible presence of water in the cylinder (we are not so hydrophobic), but in that it admits that the water, varying in quantity, is presented only temporarily, is carried away and renewed stroke by stroke, and acts chiefly as the medium between the steam and the cylinder wall. In the Alsatian explanation the action of the water raises the thermal action of the sides. In Prof. Zeuner's view, the water is permanently present and acts independently of the cylinder sides."

Recent Systematic Experiments.—Willans.

It has been quite impossible in this lecture to do more than select one or two of the most important of the experimental investigations during the last fifty years. But I should not like to omit all reference to the two series of experiments of the late Mr. P. W. Willans. Mr. Willans' work is no doubt well known to all steam engineers, and needs no detailed description. However purely practical the object Mr. Willans had in view, his experiments were made in the true spirit of scientific research. No trouble was too much to secure accuracy to the last decimal, no possible cause of error was so trivial that its investigation was reckoned unnecessary. A few experimenters, Isherwood, Gately and Kletsch and others had made experiments on a methodical system, varying a single factor at a time. Willans carried out the method of experiments in series on a scale which, till he proved that it could be done, no one would have supposed possible. There is a series of non-condensing and a series of condensing trials; in each there are trials of simple, compound, and triple engines; and for each of these, again, trials with initial pressure varied, with expansion varied, and with speed varied. The results, tabulated in the clearest way, form a quarry of scientific data, but at present, in the main, an unworked quarry. Perhaps that statement will seem surprising, and of course I am expressing only my own view, for which I claim no infallibility. What Mr. Willans might have done had he been spared, it is impossible to say. He had the most active mind and the widest experience devoted, perhaps, at any time to the study of steam problems.

Let me protest as strongly as possible, again with the reservation that I am stating my personal view, against the tendency to suppose that the great work of Willans can be summed up in a so-called Willans' law, or that that law, handy as it may be for practical steam engineers, is more than a quite subordinate part of Willans' work. The Willans' law is nothing more than the empirical descriptive statement that the relation of total steam consumption and indicated or effective horse-power can be very approximately expressed by a linear equation, for the case of an unjacketed engine working with a fixed cut-off. Further, nothing is done in Willans' papers to fix what is the linear equation for any given engine. So far as those papers go, and until some kind of theory taking account of initial condensation is discovered, we can only find the relation of steam consumption and horse-power for any given engine by making two accurate trials of the engine itself. Willans' law leaves us in regard to any given engine in the same position as an astronomer with a new comet. When the comet has been observed for a sufficient period, and some of its positions fixed, a probable orbit can be calculated. The straight-line law leaves the steam consumption of a new engine as unknown as the elliptic law the orbit of a new comet.

Willans himself says nothing whatever as to any possible rational basis for the Willans' law. He put it forward purely as the result of plotting his experiments. Later, Captain Sankey showed that the total steam consumption of an engine working adiabatically with fixed ratio of expansion would also follow nearly but not exactly a straight-line law if all clearance losses, radiation, and exhaust waste and back pressure loss were neglected.

If we assume isothermal expansion (and really so far as the area of the diagram is concerned, it matters little what law of expansion is assumed), it is easy to find a formula for the total steam consumption of an engine working without clearance loss or exhaust waste. I have found such a formula, and plotted the results both for a condensing and a non-condensing engine in the diagram. It is found that the lines plotted are not exactly, but very nearly, straight lines. That carries us a certain way, but it is an enormous jump to assume without examination that the steam wastes in the engine, amounting to from 20 to 50 per cent. of the steam used, and arising from causes of the most complex kind, depending on the volume of the clearance, the action of the cylinder wall, the loss of the toe of the diagram, the waste expansion between the cylinders, and other causes of loss, that these also can be expressed as a simple linear function of the horse-power.

Now, in the first edition of his treatise on the steam engine, which appeared in 1878, Prof. Cotterill had seriously attacked the problem of cylinder condensation from the theoretical side. Prof. Cotterill found it possible to give a partly rational, partly empirical, formula for cylinder condensation.

But, according to his formula for unjacketed simple engines, the initial condensation has a fixed ratio to the steam present at cut-off. In the diagram, lines for steam present at cut-off are given, calculated in the manner already described. Above these has been set up the condensation by Cotterill's law, and the total steam consumption at various loads is then given by a line very nearly straight and closely agreeing with a Willans' line.

The curves on the two diagrams agree well with Willans' results, and they differ from Willans' lines in being obtained entirely by calculation without experimenting on the engine. It would not be right to make too much of the coincidence, but I thought it would be interesting to show that theory and experiment converge. A good deal has yet to be explained, but the discussion in Prof. Cotterill's treatise has done more than anything else to throw light on the conditions which promote or hinder cylinder condensation, and on the means useful in securing economy of working.

Since 1845, purely scientific men, scientific experimenters, and practical engineers have all been engaged in the study of the steam engine. I do not believe that any one of the three can claim all the credit for the improvement of the steam engine to the exclusion of either of the others.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

OXFORD.—At a Congregation of the University held on Tuesday, 21st inst., the proposed Statute on Degrees for Research was passed in its final form, *nemine contradicente*. It only remains for the Statute to be passed by Convocation, and it will come into force.

At the same meeting, the addition to Statute conferring the title of Professor of Anthropology on Dr. E. B. Tylor, so long as he shall hold the office of Reader in Anthropology, received the final sanction of Congregation. A proposal recognising Anthropology as a subject for the Final-Honour School of Natural Science was then brought forward. After some debate the preamble was passed. Placets 24, non-placets 16.

CAMBRIDGE.—The following is the Speech delivered by the Public Orator, Dr. Sandys, in presenting for the honorary degree of Doctor in Science, Mr. Francis Galton, F.R.S.

Sedes olim sibi notas hodie revisit alumnus noster, qui flumine Nilo quondam explorato, et Africa Australi postea perlustrata, velut alter Mercurius omnium qui inter loca deserta et inhospita peregrinantur adiutor et patronus egregius exstitit. Idem, velut alter Aeolus, etiam ipsos ventos caelique tempestates suae provincae audacter adiunxit. Hodie vero Academiae nemora nuper procellis nimium vexata non sine misericordia contemplatus, e frondibus nostris caducis capiti tam venerabili coronam diu debitam imponi patitur. Tempestatum certe in scientia iamdudum versatus, ventorum cursus tabulis fidelibus olim mandavit, gentesque varium caeli morem praediscere docuit, laudem philosopho cuidam antiquo a Nubium choro Aristophanico quondam tributam uno saltem verbo mutato meritus:—*οὐ γὰρ ἂν ἄλλῳ γ' ὑπακούσαιμεν τῶν νῦν μετεωρολογούντων.* Longum est avorum et proavorum ingenia magna in ipsorum progenie continuata ab hoc viro, Caroli Darwinii cognato, virorum insignium exemplis illustrata percensere. Longum est tot honores titulosque ab ipso per tot annos cumulatos commemorare. Hoc autem in loco, eloquentiae eius undecim abhinc annos conscio, instituti anthropologici praesidem non corporis tantum sed etiam mentis humanae mensorem appellaverim. Inter antiquos quidem celebratum erat illud Protagorae, omnium rerum mensuram esse hominem. Inter recentiores autem notum est hunc praesertim virum hominum omnium, imprimis pessimorum, mensuram ad amussim velle exigere. Ceterum plura hodie dicere supervacaneum est; constat enim ne optimorum quidem virorum a laudibus abesse debere mensuram.

Duco ad vos virum de scientia anthropologica et meteorologica praeclare meritum, caeli et terrae indagatorem indefessum, studiorum denique geographicorum etiam inter nosmet ipsos fautorem insignem, FRANCISCUM GALTON.

Lord Acton will deliver his inaugural lecture as Regius Professor of Modern History on June 11, at noon.

Prof. Lewis announces courses of lectures and demonstrations in Crystallography during the Long Vacation, beginning on July 9.

Prof. Roy announces a practical course in Bacteriology, to be given by Dr. Wesbrook and Dr. Lazarus-Barlow, in the Long Vacation, beginning on July 8. There will also be a course of lectures with practical work in Elementary Pathology, beginning on July 9.

Mr. H. F. Baker, Fellow and Lecturer of St. John's College, has been appointed University Lecturer in Pure Mathematics, in the place of Dr. Forsyth, now Sadlerian Professor.

A YEAR ago a committee, representing various educational bodies, was formed, at the instance of the Association of Headmasters, to formulate an examination syllabus on which to award major scholarships, offered by County Councils and similar bodies, and tenable at places of higher education. All who know how very different are the scholarship schemes of the County Councils, agree that a larger degree of uniformity should prevail in the examinations held for the purpose of selecting candidates for the scholarships. The Association's scheme for major scholarships has been so drawn up that only candidates showing ability and intelligence distinctly above the average can be elected. Candidates must not be more than eighteen years of age in case of boys, and nineteen years in case of girls, and must have passed a preliminary examination to test their general education before they can compete for the scholarships. The scheme provides that the final scholarship examination shall consist of three groups—science, commercial, and literary—each containing obligatory and optional subjects. The subjects of examination for science scholarships have been carefully selected, and with due consideration to the claims of practical work.

THE second annual report of the Technical Education Board of the London County Council appears in the *Technical Education Gazette*. A sum of nearly £15,000 was granted, during the year covered by the report, to intermediate and secondary schools. The fact that the Board has now over six hundred scholars attending these schools indicates how seriously it is concerned with technical education. While the question of the Teaching University for London has been in abeyance, the Board has not been able to act upon the proposal in Mr. Llewellyn Smith's report to contribute £10,000 a year towards the technical departments of the University. It was thought undesirable, however, to wholly abstain from helping institutions of university rank until the establishment of the Gresham University, so a grant of £1000 was made to University College, and £500 to Bedford College. The polytechnic institutes are rapidly increasing in extent and advancing in efficiency. The total annual expenditure of the eight institutions open last year amounted to about £90,000, their total number of students to over 27,000, and their aggregate number of separate classes or courses of lectures to over 1250. It is believed that the polytechnics now give probably nine-tenths of all the evening instruction in technological subjects in London, and three-fourths of the evening science instruction. All this represents an immense advance on the state of things five years ago, and indicates that the Board has remarkably extended the facilities for technical education during the two years it has been at work.

THE fourth annual report (2 vols.) of the U.S. Commissioner of Education has been received. The volumes provide a mine of information on educational methods in France, Austria, Germany, Sweden, Switzerland, Alaska, the United States, and our own country. A full account is given of the character and development of German Universities, by Prof. Paulsen, of Berlin, supplemented by a statistical review of the subject by Prof. Conrad, of Halle. School museums in various parts of the world form the subject of a separate chapter. There is also an elaborate paper in which methods of physical training are very fully treated.